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by I. Ya. Tarnovskiy, O. A. Ganago, and R. A. Vaysburd

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INVESTIGATION OF METAL FLOW DURING UPSETTING WITH BACKING RINGS BY MEANS OF THE PRINCIPLES OF VARIATIONS

- USSR -

[Following is a translation of an article by I. Ya. Tarnovskiy, O. A. Ganago, and R. A. Vaysburd in the Russian-language periodical Izvestiya Vysshikh Uchebniykh Zavedeniy, Chernaya Metallurgiya (News of the Higher Educational Institutions, Ferrous Metallurgy), Moscow, No. 5, May 1960, Pages 55-60.]

Upsetting in backing rings is one of the widely used operations of free forging and also represents a stamping process for very simple parts. The investigation of this process permits the study of the fundamental principles of metal flow in the cavity of a die and the flash gutter.

A number of theoretical and experimental studies have been devoted to the investigation of metal flow in backing rings during forging [1, 2, 3].

In the present work, an experiment was made using the principles of variations to obtain a theoretical solution for the calculation of metal flow in backing rings during forging which would be suitable for the practical use of technologists.

The principle of the minimum of the full energy of deformation and the Ritsa method are used in the solution [4,5].

During upsetting in backing rings (Figure 1), there is initially a contraction in the height of the central portion of the blank h_n. The intensity of this contraction declines in proportion to the upsetting and finally h_n begins to expand and then the intensity of expansion increases in proportion to the upsetting. This testifies to the non-monotonic character of metal flows in a given process.

Only monotonic processes of plastic changes in form [6] are determined in the theory of plasticity; therefore, it is natural to divide the entire upsetting process into stages. In each one, the conditions of monotony are fulfilled, i.e., a rigid kinematic system of metal flows exists.

Let us examine the deformed condition of a forging during continuous minor upsetting Δh at any intermediate moment (Figure 1). In view of the axial symmetry of the problem, it is convenient

to use a cylindrical system of coordinates in the solution. For the sake of simplicity, let us accept the hypothesis of flat cross-sections, i.e., let us suppose that the elements of displacement and deformation do not depend on the height of coordinate z. Then according to the correlation of a mechanically uniform media [5] we obtain for the first part

$$\varepsilon_{z_1} = -a;\ U_{z_1} = -az;\ U_{r_1} = \tfrac{1}{2}ar;$$
$$\varepsilon_{r_1} = \tfrac{1}{2}a;\ \varepsilon_{\varphi_1} = \tfrac{1}{2}a;\ \Gamma_{rz_1} = 0 \tag{1}$$

where a is the relative change in the height of the first part $\frac{\Delta h_1}{h}$.

This magnitude is a variable parameter which is definied below from the conditions of the minimum of the full energy of deformation.

Knowing a, one can determine the amount of metal flowing from the central part of the forging over to the periphery; in this case $a > 0$.

In the transfer of metal from the peripheral part to the central part, there is an increase in the height of the central part and a becomes less than 0.

In the absence of a transfer of metal from one part of the forging to another, the height of the central part of the forging remains constant and $a = 0$.

After determining the magnitude a, one can find all the dimensions of the forging at any given moment of deformation from the condition of constancy of the volume of deformed metal.

The work of internal forces in the first part

$$A_1 = \tau_s \int_0^{2\pi}\int_0^{h}\int_0^{R_n} \Gamma_1 r\,dr\,dz\,d\varphi$$

where $\Gamma_1 = \sqrt{4\varepsilon_r^2 + 4\varepsilon_\varphi^2 + 4\varepsilon_r\varepsilon_\varphi + \gamma_{rz}^2} =$

$= /a/\sqrt{3} =$ the intensity of deformation of displacement.

Integrating, we obtain

$$A_1 = \sqrt{3}\pi\tau_s /a/ hR_n^2. \tag{2}$$

In connection with the adoption of the hypothesis of flat cross-sections for simplifying the solution of the problem, the functions for the elements of dislocations undergo a break at the boundary between the first and fourth parts (Figure 1). Actually, such breaks are absent, but the deformation in the volume of the first part is not uniform. The grains, vertical before deformation, bend and additional work is expended on this. This work is taken into account in the form of the shear strain at the boundary between the first and the fourth parts:

$$A_2 = \tau_s \int_0^{2\pi} \int_0^{R_n} U_{r_1} r dr d\varphi = \frac{1}{3}\pi \tau_s /a/ R_n^3. \quad (3)$$

Analogously for the second part

$$\varepsilon_{z_2} = -\varepsilon; \; U_{z_2} = -\varepsilon z; \; U_{r_2} = \frac{a}{2} \frac{R_n^2}{r} + \frac{\varepsilon}{2} \frac{r^2 - R_n^2}{r};$$

$$\varepsilon_{r_2} = -\frac{a}{2} \frac{R_n^2}{r^2} + \frac{\varepsilon}{2}\left(1 + \frac{R_n^2}{r^2}\right); \; \varepsilon_{\varphi_2} = \frac{a}{2} \frac{R_n^2}{r^2} + \frac{\varepsilon}{2} \quad (4)$$

$$\left(1 - \frac{R_n^2}{r^2}\right); \; \gamma_{rz_2} = 0$$

where $\varepsilon = \frac{\Delta h}{h}$ — the relative reduction of the peripheral part of the forging (Figure 1);

U_{r_2} — obtained from the conditions of constancy of the volume taking account of the flow of metal from one part of the forging to another.

The work of internal forces in the second part

$$A_3 = \tau_s \int_0^{2\pi} \int_0^{h} \int_{R_n}^{R} \Gamma_2 r dr dz d\varphi,$$

where

$$\Gamma_2 = \sqrt{3\varepsilon^2 + (a - \varepsilon)^2 \frac{R_n^4}{r^4}}.$$

Integrating, we obtain

$$A_3 = \sqrt{3}\pi\tau_s\varepsilon h \left[\sqrt{R^4 + a_1^2} - \sqrt{R_n^4 + a_1^2} + a_1 \ln \frac{(a_1 + \sqrt{R_n^4 + a_1^2})\ R^2}{(a_1 + \sqrt{R^4 + a_1^2})\ R_n^2}\right] \quad (5)$$

where

$$a_1^2 = \frac{1}{3} R_n^4 \left(\frac{a}{\varepsilon} - 1\right)^2 .$$

The work of shearing on the vertical plane between the first and second parts

$$A_4 = 2\pi R_n \tau_s \int_0^h \left| U_{z_1}\Big|_{r=R_n} - U_{z_2}\Big|_{r=R_n} \right| dz = \pi R_n \tau_s h^2 (\varepsilon - a). \quad (6)$$

In calculating the work of the forces of external friction on the contact surface, it is necessary to examine separately the cases with a contraction of the height of the central part of the forging ($a > 0$) and those with an expansion ($a < 0$).

Indeed, with $a > 0$ in the peripheral part of the forging (parts 2 and 3) the metal flow will be uni-lateral and, therefore, the frictional forces will be identical on all contact surfaces.

In this case, the work of the force of contact friction on the second and third parts

$$A_5 = 2\mu\tau_s \int_0^{2\pi} \int_{R_n}^{R} U_{r_2} r dr d\varphi .$$

As a result of integration, we have

$$A_5 = 4\pi\mu\tau_s \left[\frac{\varepsilon}{6}(R^3 - R_n^3) + \frac{1}{2}(a - \varepsilon)(R - R_n)R_n^2\right] \quad (7)$$

In the case where $a < 0$, the metal should flow into the central part of the forging in order to increase the height h_n.

In addition, the flow of metal in the peripheral part naturally must be bilateral. Such a kinematic scheme of metal flow is confirmed by experiments with a coordinated grid and was first discovered by A. F. Golovin [1].

We shall call the cylindrical division of the metal flow in the peripheral part of the forging critical (or neutral).

The connection of parameter a with the radius of the critical (neutral) surface R_K is determined from the condition of the constancy of volume:

$$R_k = R_n \sqrt{1 - \frac{a}{\varepsilon}} \qquad (8)$$

We shall find the work of the force of friction in the following way:

$$A_5 = 2\mu\tau_s \left[\int_0^{2\pi} \int_{R_n}^{R_n\sqrt{1 - \frac{a}{\varepsilon}}} /U_{r_2}/ r\,dr\,d\varphi + \int_0^{2\pi} \int_{R_n\sqrt{1 - \frac{a}{\varepsilon}}}^{R} /U_{r_2}/ r\,d\varphi\,dr \right].$$

Integrating, we obtain

$$A_5 = 2\pi\mu\tau_s \left[\frac{1}{3} R^3 - R \cdot R_n^2 \left(1 - \frac{a}{\varepsilon}\right) + \frac{2}{3} R_n^3 \sqrt{\left(1 - \frac{a}{\varepsilon}\right)^3} \right] \qquad (9)$$

The strain of internal forces and the forces of friction in the fourth part (See Figure 1) is connected with the presence of a stamping taper and is therefore very small. As numerous calculations indicate, the variation in the strain of internal and external forces in the fourth part are very small in relation to the variations of other strains. Therefore, in order to simplify the given task, we shall disregard the strain variations in the fourth part.

The complete work of deformation is A, as the sum of the components, determined by equations (2), (3), (5), (6) and (7) for cases where a 0 and equations (2), (3), (5) and (9) where a 0.

Taking $a > 0$ and differentiating according to its complete work of deformation, we obtain after mathematical transformation

$$\frac{h^2}{R_n^2} - (\beta + \sqrt{3})\frac{h}{R_n} - 2\mu\left(\frac{R}{R_n} - 1\right) - \frac{1}{3} = 0, \qquad (10)$$

where

$$= 1_n \frac{\frac{R_n^2}{R^2}\left(1 - \frac{a}{\varepsilon}\right) + \sqrt{3 + \frac{R_n^4}{R^4}\left(1 - \frac{a}{\varepsilon}\right)}}{1 - \frac{a}{\varepsilon} + \sqrt{3 + \left(1 - \frac{a}{\varepsilon}\right)^2}} \qquad (11)$$

When $a < 0$, an analogous equation has the form

$$\frac{h^2}{R_n^2} - (\beta - \sqrt{3})\frac{h}{R_n} - 2\mu\left(\frac{R}{R_n} + 1 - 2\sqrt{1 - \frac{a}{\varepsilon}}\right) + \frac{1}{3} = 0. \qquad (12)$$

Figure 2 represents graphs for $\frac{a}{\varepsilon}$, depending on $\frac{D_n}{}$ and $\frac{H}{D}$ when $\mu = 0.5$, constructed from equation (10) for a $D > 0$ and from equation (12) for $a < 0$.

In the process investigated a cannot be greater than unity. From Figure 2, it is clear that for ε each value D_n has a range of values H in the limits of which $\frac{a}{\varepsilon} = 0$, i.e. $\frac{D}{D_n}$ there is no change in the height of the central part of the forging. This is confirmed by experimental data.

Thus, the entire process of upsetting in backing rings in the most general case can be divided into four stages.

The first stage is characterized by the complete drawing of the central part of the forging ($\frac{a}{\varepsilon} = 1$).

In the second stage, the central part of the forging h_n becomes smaller, but the intensity of this contraction declines ($0 < \frac{a}{\varepsilon} < 1$).

In the third stage, the height of the central part of the forging remains constant ($\frac{a}{\varepsilon} = 0$).

In the fourth stage, the height of the central part of the forging increases ($\frac{a}{\varepsilon} < 0$).

L. A. Shofman in his studies indicated the presence of these four stages [3].

The general solution to the problem posed is determined from the differential equation

$$\frac{dh}{dR} = \frac{2Rh}{R^2 - R_n^2\left(1 - \frac{a}{\varepsilon}\right)}, \qquad (13)$$

constructed from the conditions of constancy of volume. The value a is determined from equations (10) and (12).

The differential equation (13) is integrated without difficulty for the first and third stages of upsetting. For the other stages, only an approximate solution is possible.

In the present study, integration was carried out by the Adams method [7]. Figures 3 and 4 present graphs for $\frac{D}{D_o}$ and $\frac{H_n}{H_o}$ depending on the relationship of $\frac{D_n}{D_o}$ and $\frac{H}{H_o}$ when $\frac{D_o}{H_o} = 2$.

Corresponding graphs have also been obtained for other relationships of $\frac{D_o}{H_o}$, which are not presented here.

With the aid of these graphs it is not difficult to calculate the changes in form of a forging during upsetting to a given size.

The reverse problem can be solved by the selection method. Knowing the dimensions of the finished forging, we determine the relationship of the dimensions of the blank which provide the optimum forging conditions by the method of successive approximations.

Experimental verification of the regularities obtained have provided satisfactory results.

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FIGURE APPENDIX

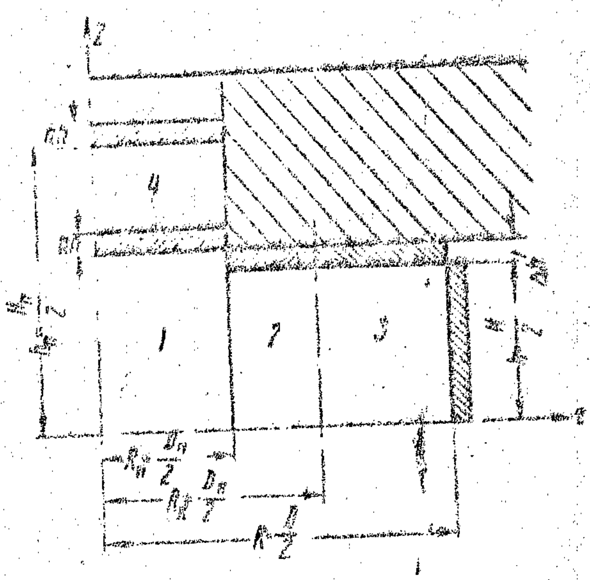

Figure 1. Diagram of the Process of Upsetting in Backing Rings.

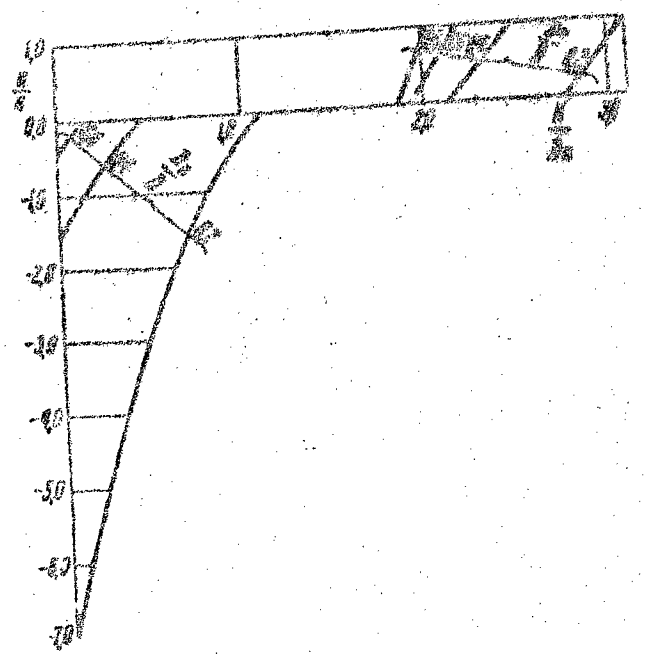

Figure 2. The Dependence of $\frac{a}{\ell}$ on $\frac{D_n}{D}$ and $\frac{H}{D_n}$

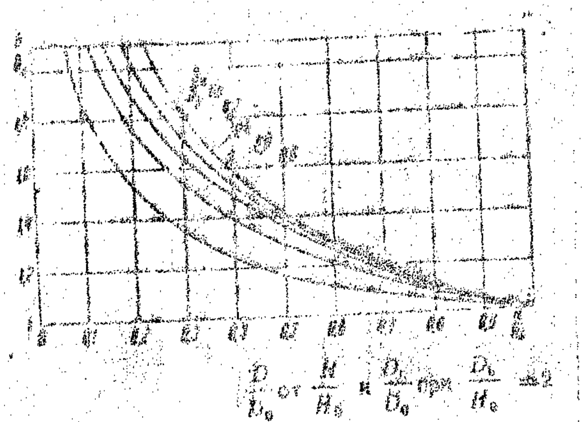

Figure 3. The Dependence of $\frac{D}{D_o}$ on $\frac{H}{H_o}$ and $\frac{D_n}{D_o}$ when $\frac{D_o}{H_o} = 2$.

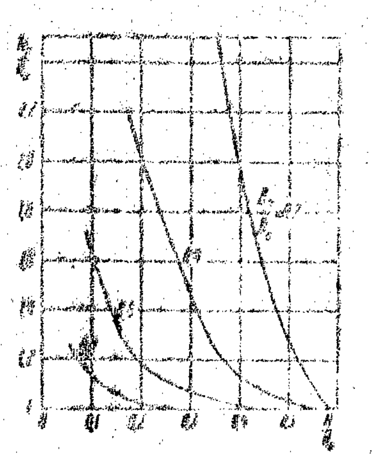

Figure 4. The Dependence of $\frac{H_n}{H_o}$ on $\frac{H}{H_o}$ and $\frac{D_n}{D_o}$ when $\frac{D_o}{H_o} = 2$.

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